Lecture 21: 04/04/2024

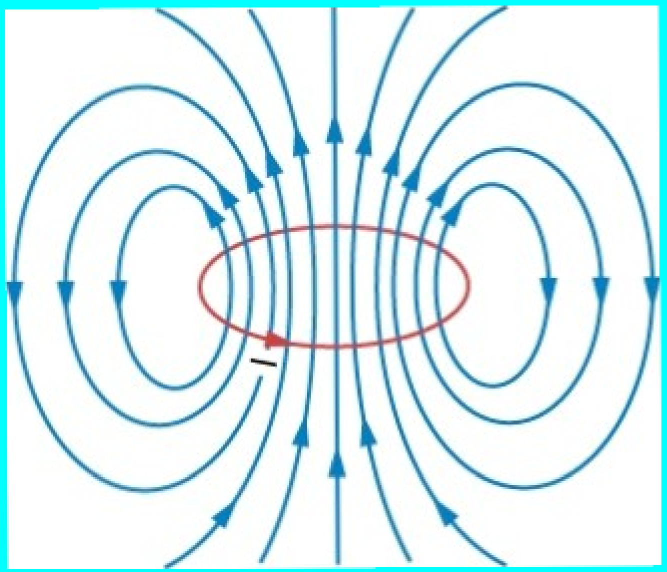
- Announcements
  Grade Change day is April 10 (Next Wednesday)
  Exams back Tuesday
  “Locked grades in canvas” “Aussie system”

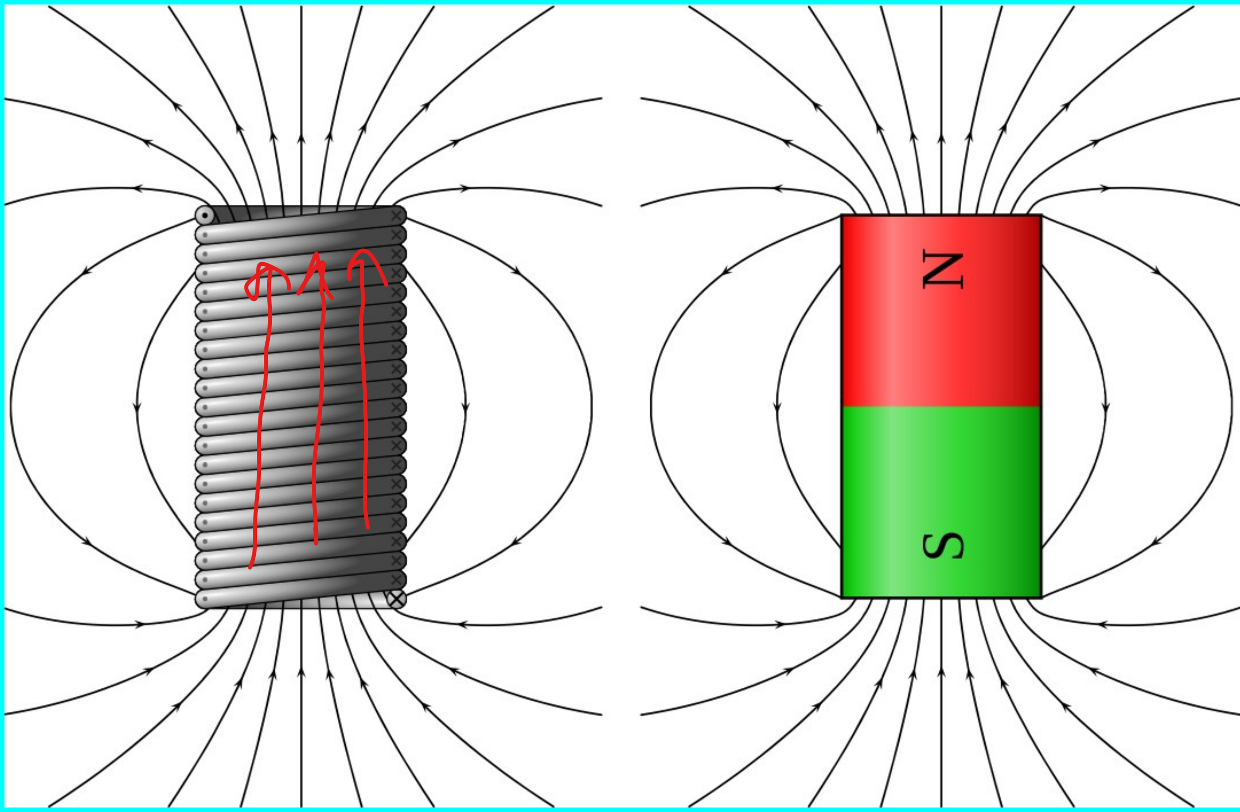
- Last Time
  Exam

- Today
  Magnetism
  Motors

Electromagnets

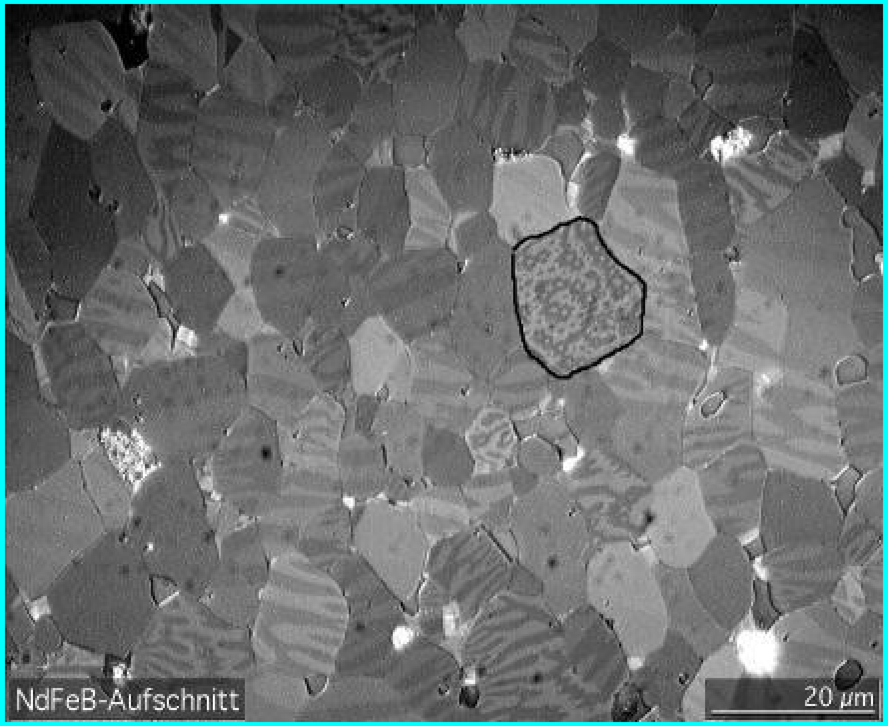
- A loop of wire is a basic electromagnet
- Many loops of wire (a coil or "solenoid") is a better electromagnet.

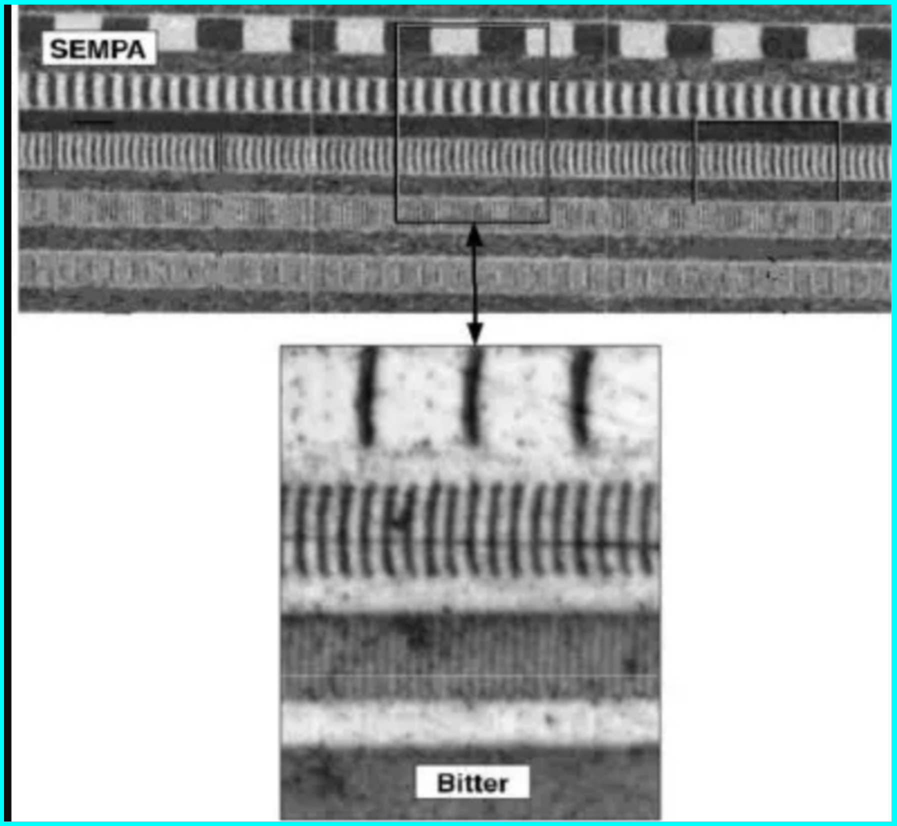




Electromagnets and “Regular magnets”

- A loop of wire is a basic electromagnet
- Many loops of wire (a coil or “solenoid”) is a better electromagnet.
- Atoms with orbiting unpaired electrons are quantum electromagnets.
- They have magnetic “moments”
- Groups of atoms get together and make magnetic “domains”
- You “magnetize” iron by lining up its domains by exposing it to a strong magnet or by wrapping wire around it.

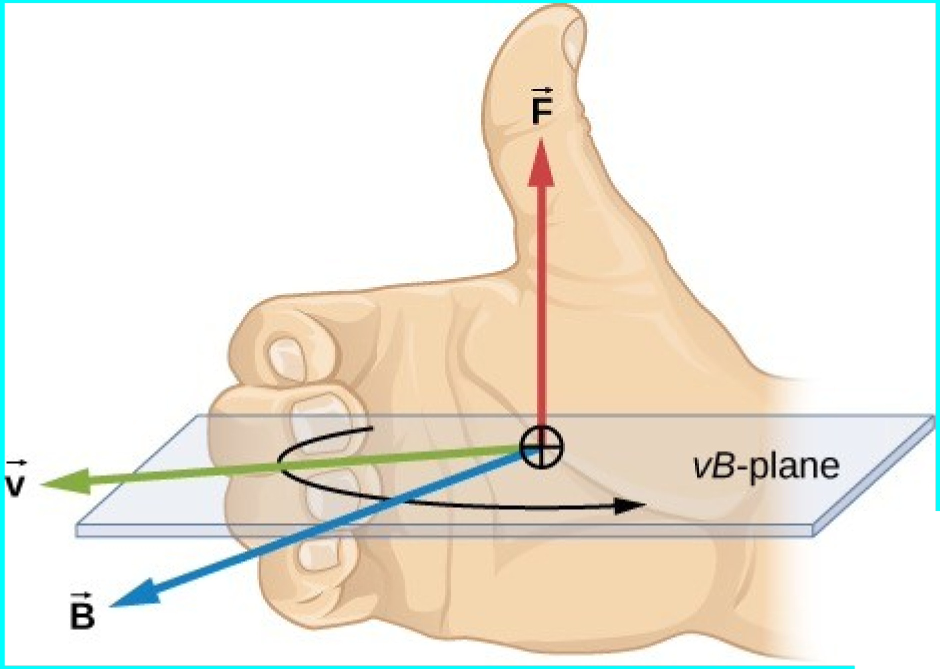

NdFeB-Aufschnitt
20 µm


SEMPA
Bitter

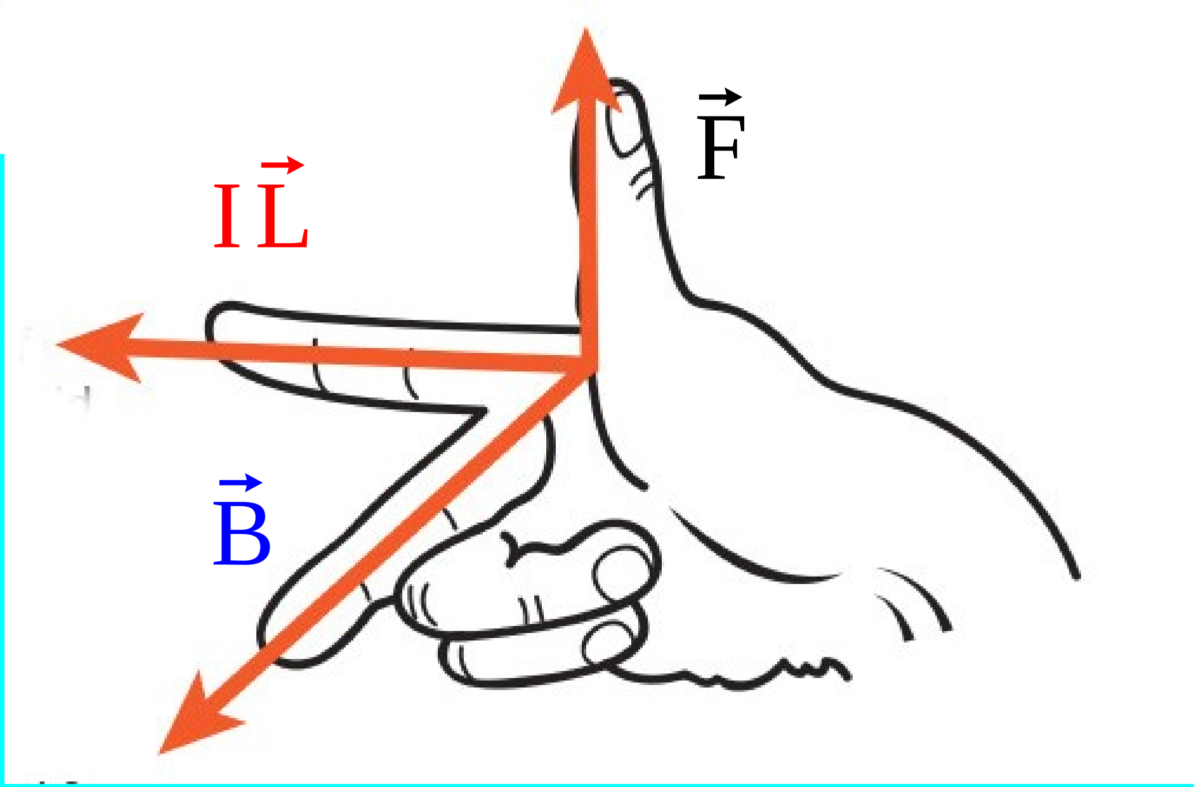
Equations of Magnetic Force

$$\vec{F} = Q\,\vec{v} \times \vec{B} \quad \text{Force on charge Q}$$

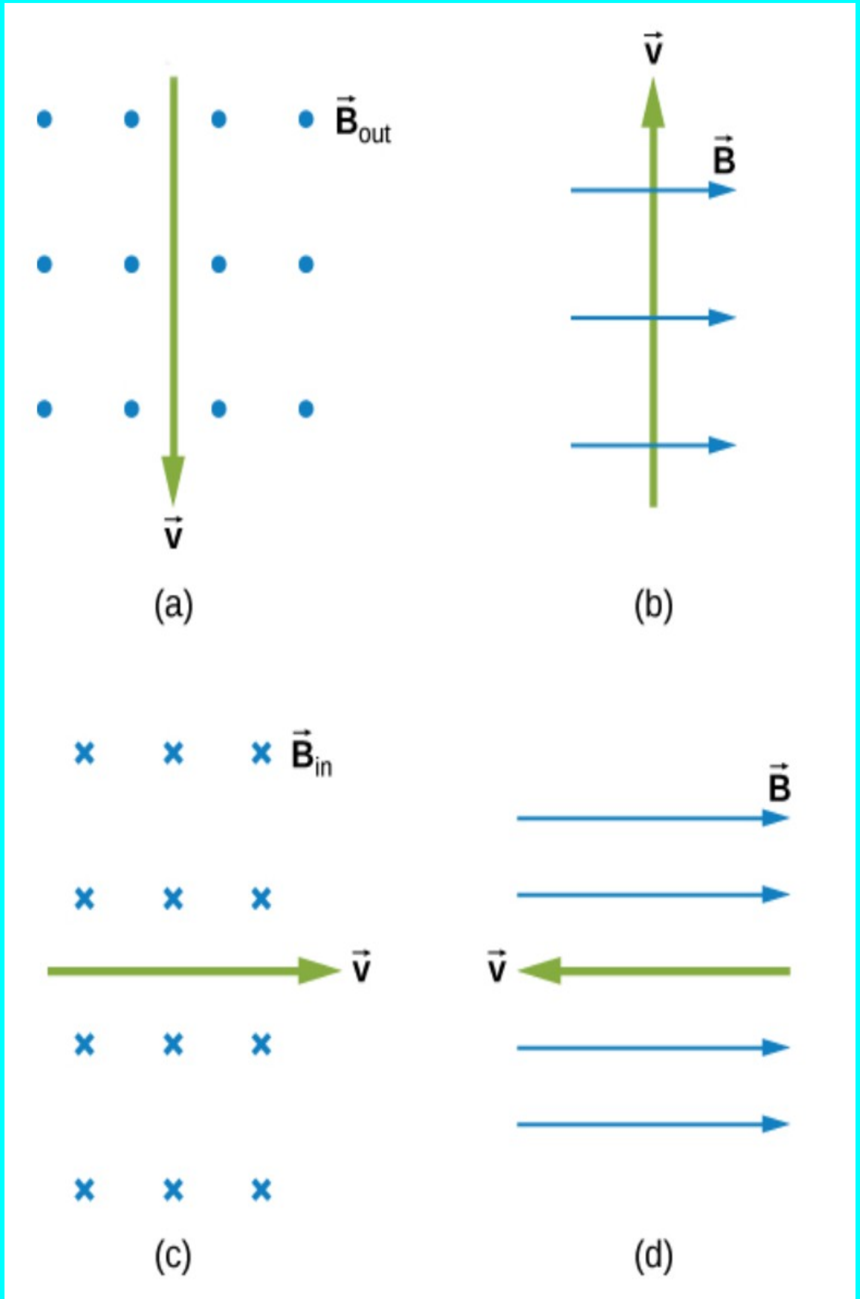
$$\vec{F} = I\,\vec{L} \times \vec{B} \quad \text{Force on current I}$$



$$\vec{F} = I\vec{L} \times \vec{B}$$



Which of these charges experiences zero magnetic force?



(A)

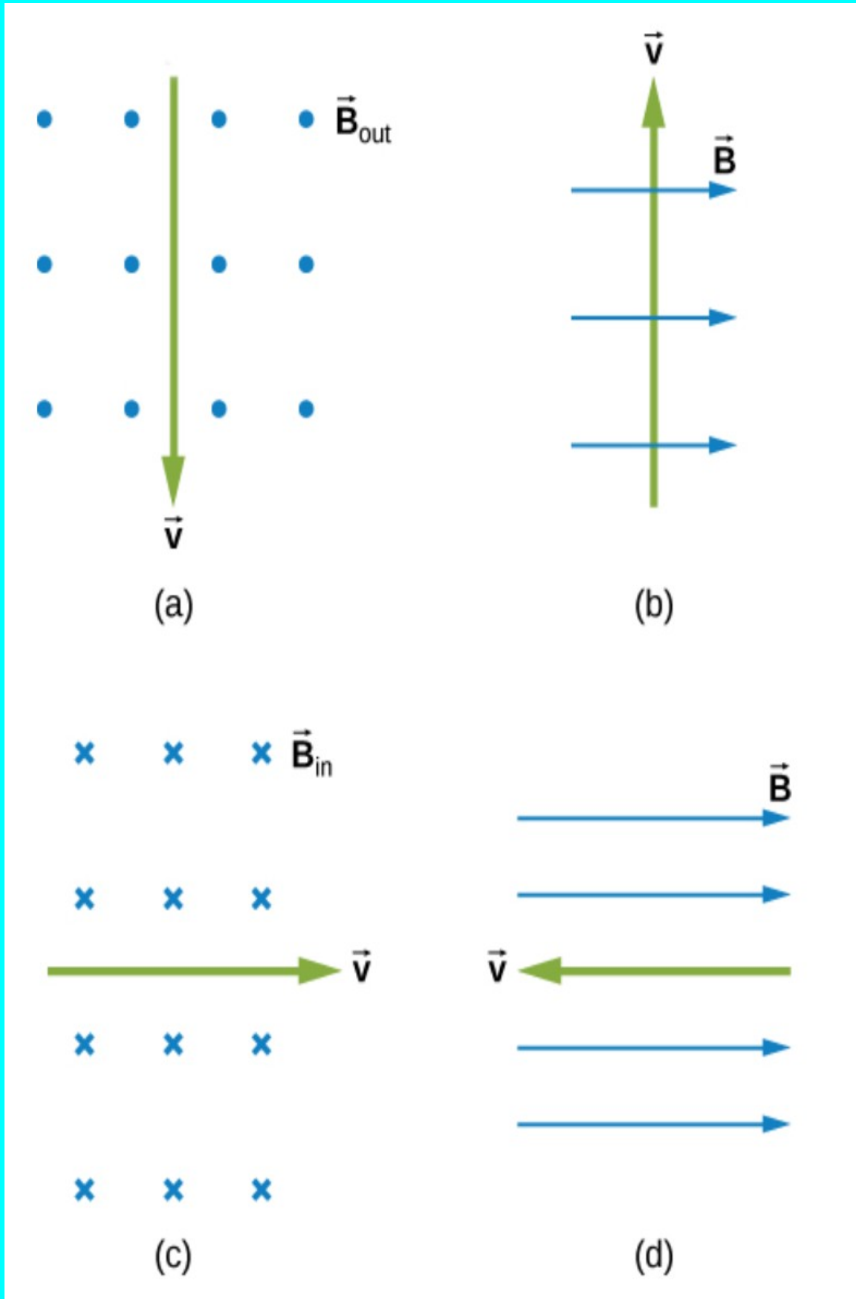
(B)

(C) $qvB\sin\theta$

(D)

$F = q\vec{v} \times \vec{B}$

Which of these positive charges experiences magnetic force to the left?



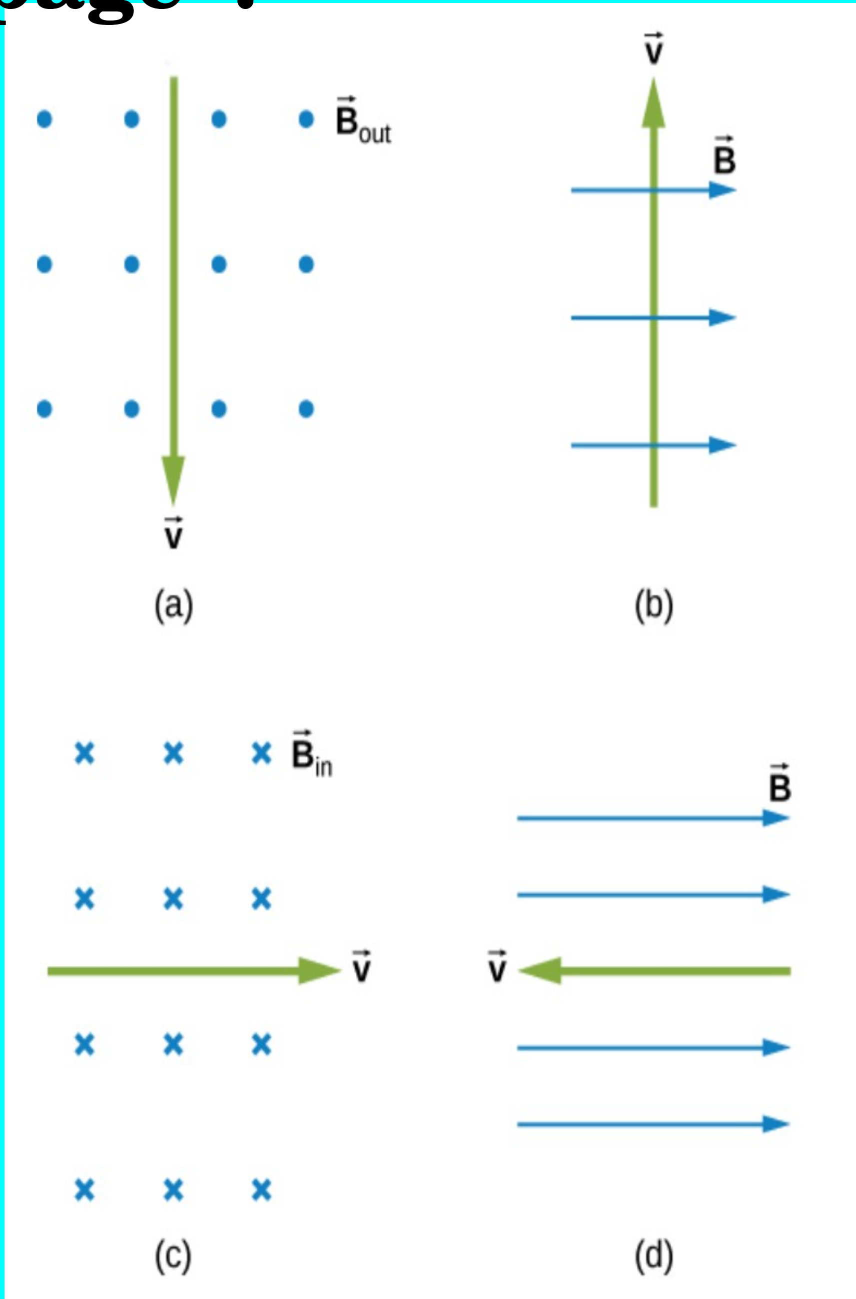
(A)

(B)

(C)

(D)

Which of these negative charges experiences magnetic force “out of the page”?



(A)

(B)

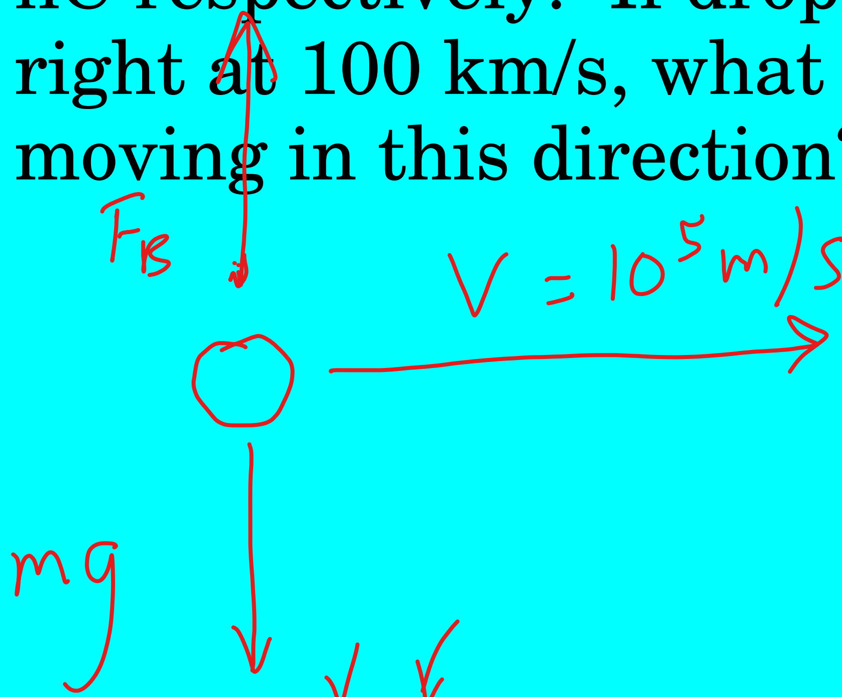
(C)

(D)

Problem 11-61

$W = \vec{F} \cdot \Delta\vec{r} = F \Delta r \cos\theta$

- Mass and charge of a water drop are 0.1 mg and 50 nC respectively. If droplet moves horizontally to the right at 100 km/s, what magnetic field will keep it moving in this direction?

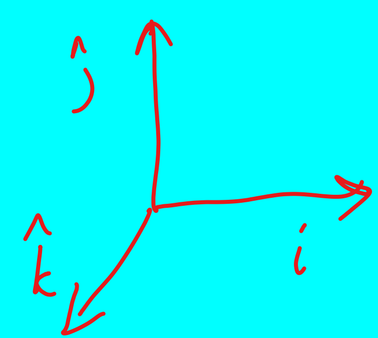


$F_B = mg$

$\vec{F}_B = q\vec{v} \times \vec{B}$ $-k$

$F = qvB\sin\theta$

$mg = qvB$



Mag. Force

- A 1 mC charge is moving at 1000 m/s at 45 degrees to a magnetic field of 1 Tesla. The force magnitude is?

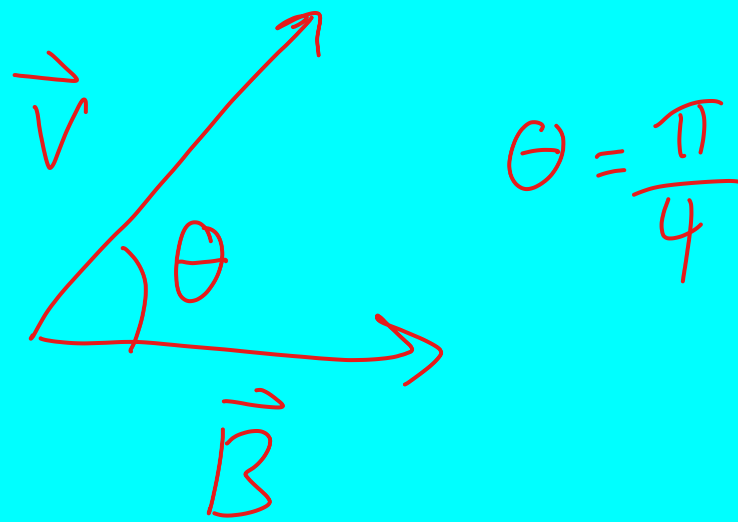
  (A) 1 N

  (B) 7 N

  (C) 0.7 N

  (D) 1000 N

  (E) 45 N



$F = qvB\sin\theta$

$(10^{-3})(10^{3}\,m/s)(1\,T)(.707)$

C

Electric fields are calculated with Coulomb's law or Gauss's Law

$$\vec{E} = \sum_i k \frac{q_i}{r_i^2} \hat{r}_i$$

$$\oint \vec{E} \cdot d\vec{a} = \frac{Q_{enc}}{\epsilon_0}$$

$$\frac{1}{4\pi\epsilon_0} \frac{q}{r^2} \hat{r}$$

$$\mu_0 = 4\pi \times 10^{-7}$$

Magnetic Fields are calculated with the Biot-Savart Law or Ampere's Law

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{l} \times \hat{r}}{r^2}$$

$$\oint \vec{B} \cdot d\vec{l} = \mu_0 I$$

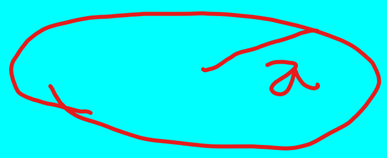
$$\oint \vec{B} \cdot d\vec{a} = 0$$

Equations of Magnetism

$\vec{F} = Q\,\vec{v} \times \vec{B}$ Force on charge Q

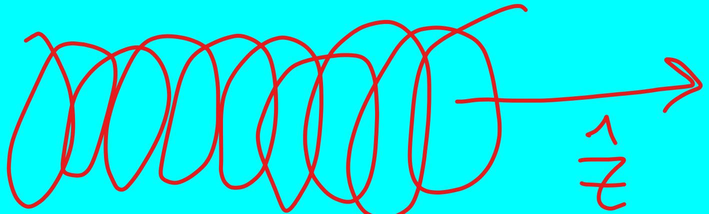
$\vec{F} = I\,\vec{L} \times \vec{B}$ Force on current I

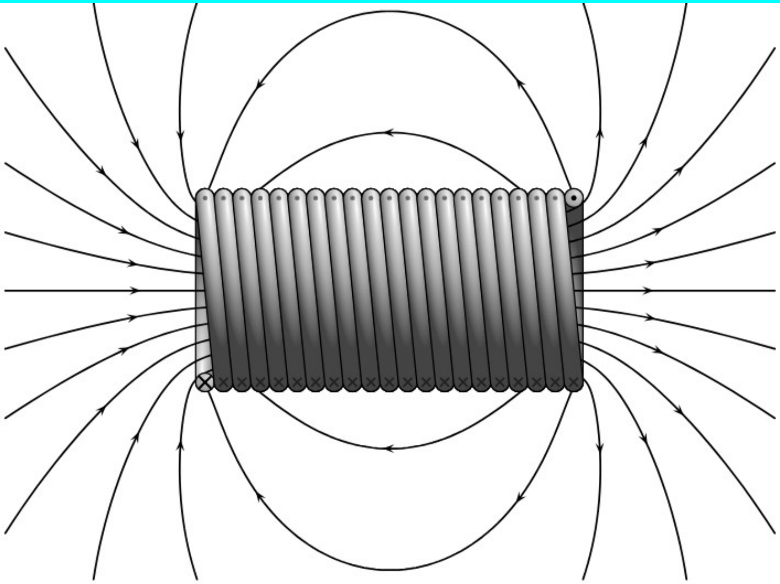
$\vec{B} = \dfrac{\mu_0 I}{2\pi r}\hat{\phi}$ Field of Infinite wire

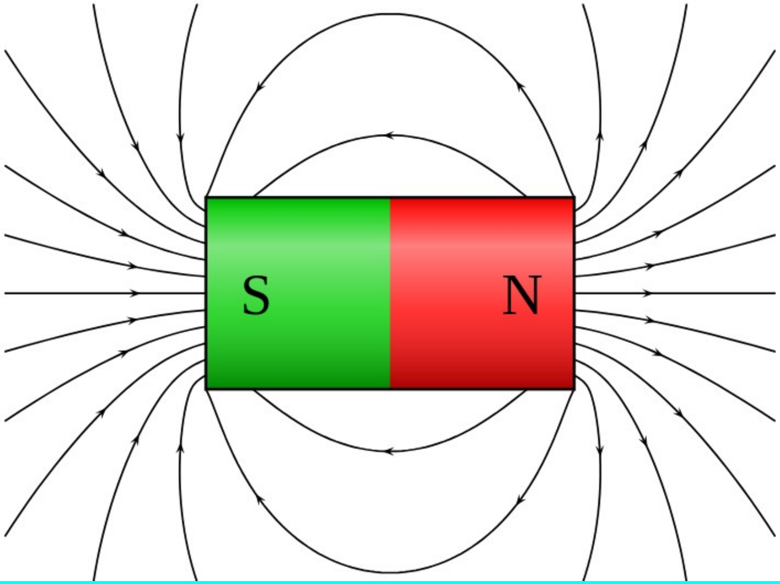


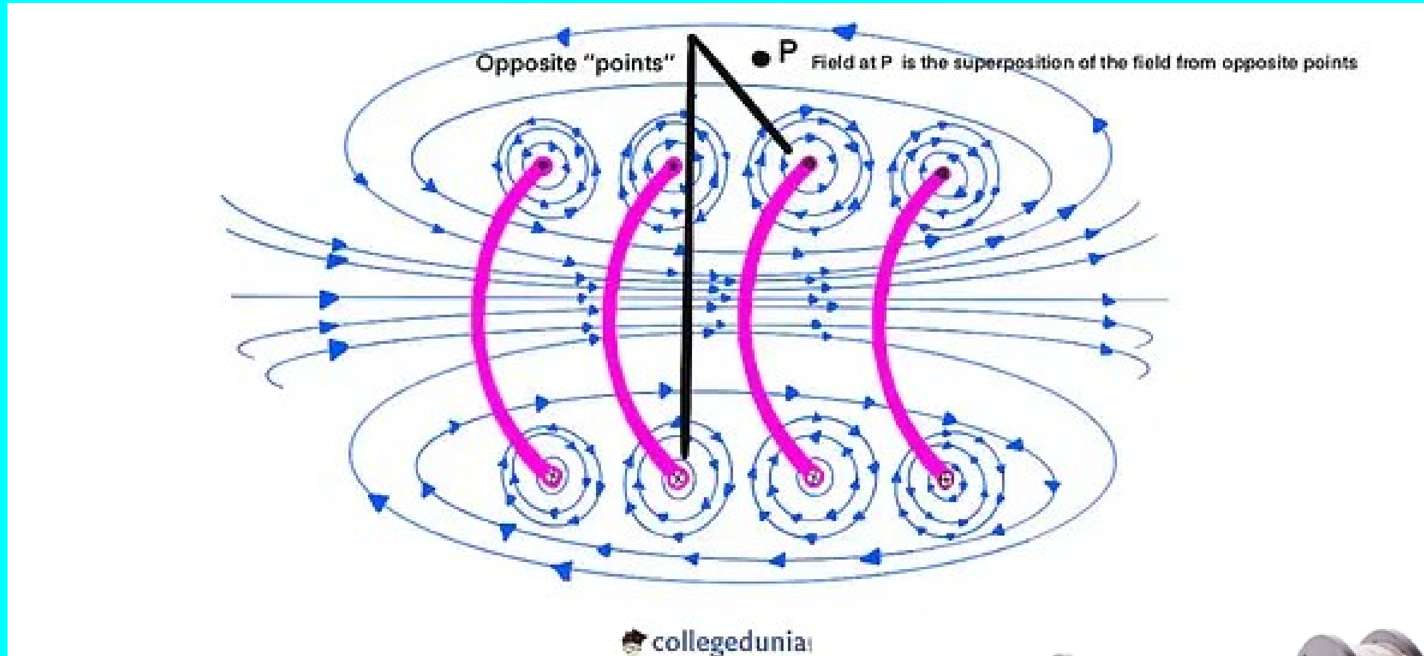
$\vec{B} = \dfrac{\mu_0 I}{2a}\hat{z}$ Field in center of wire loop

$\vec{B} = \mu_0 n I \hat{z}$ Field of an infinite coil (solenoid)



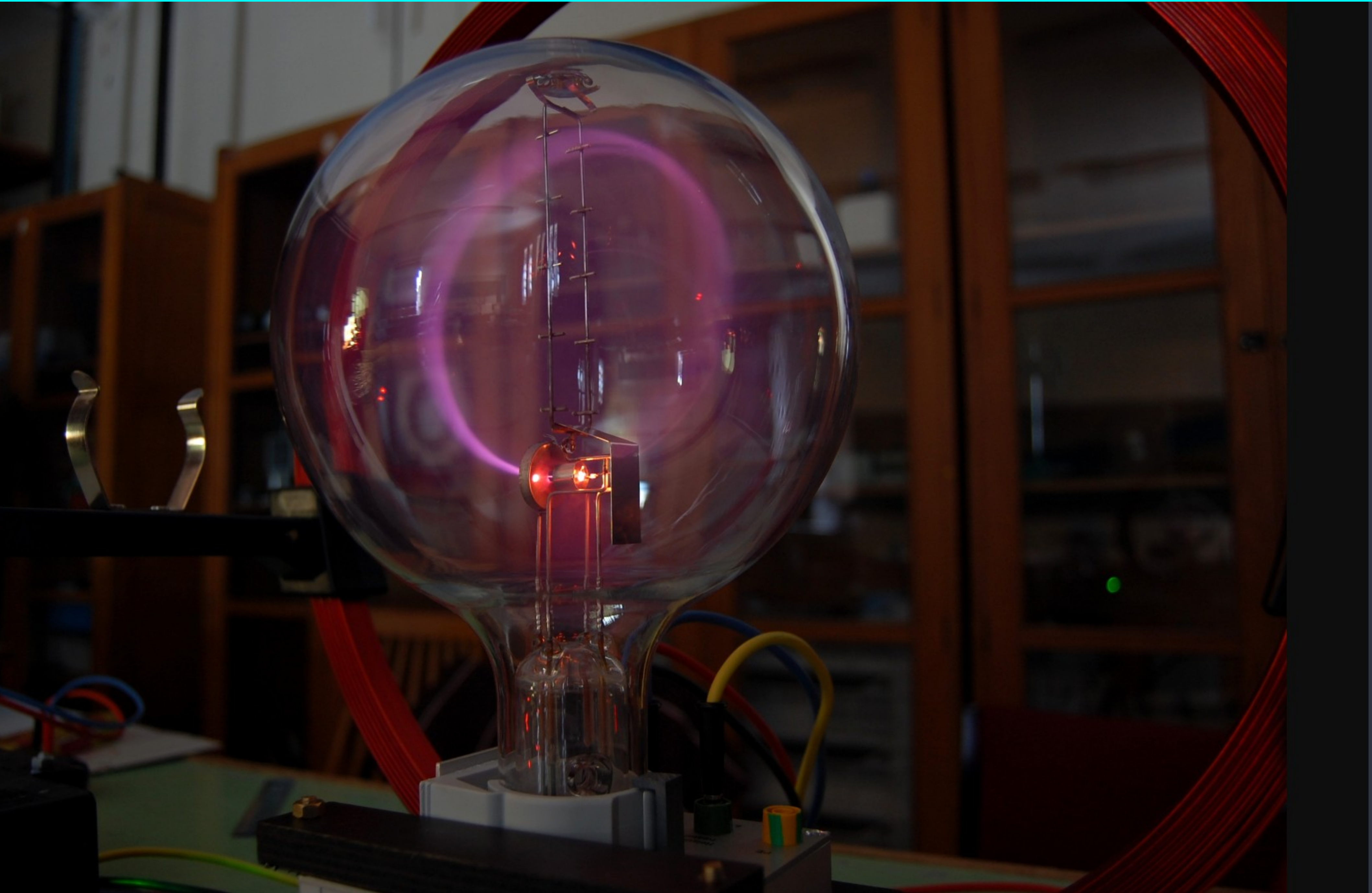



S
N



Opposite "points"
P
Field at P is the superposition of the field from opposite points
collegedunia

This Week's Lab

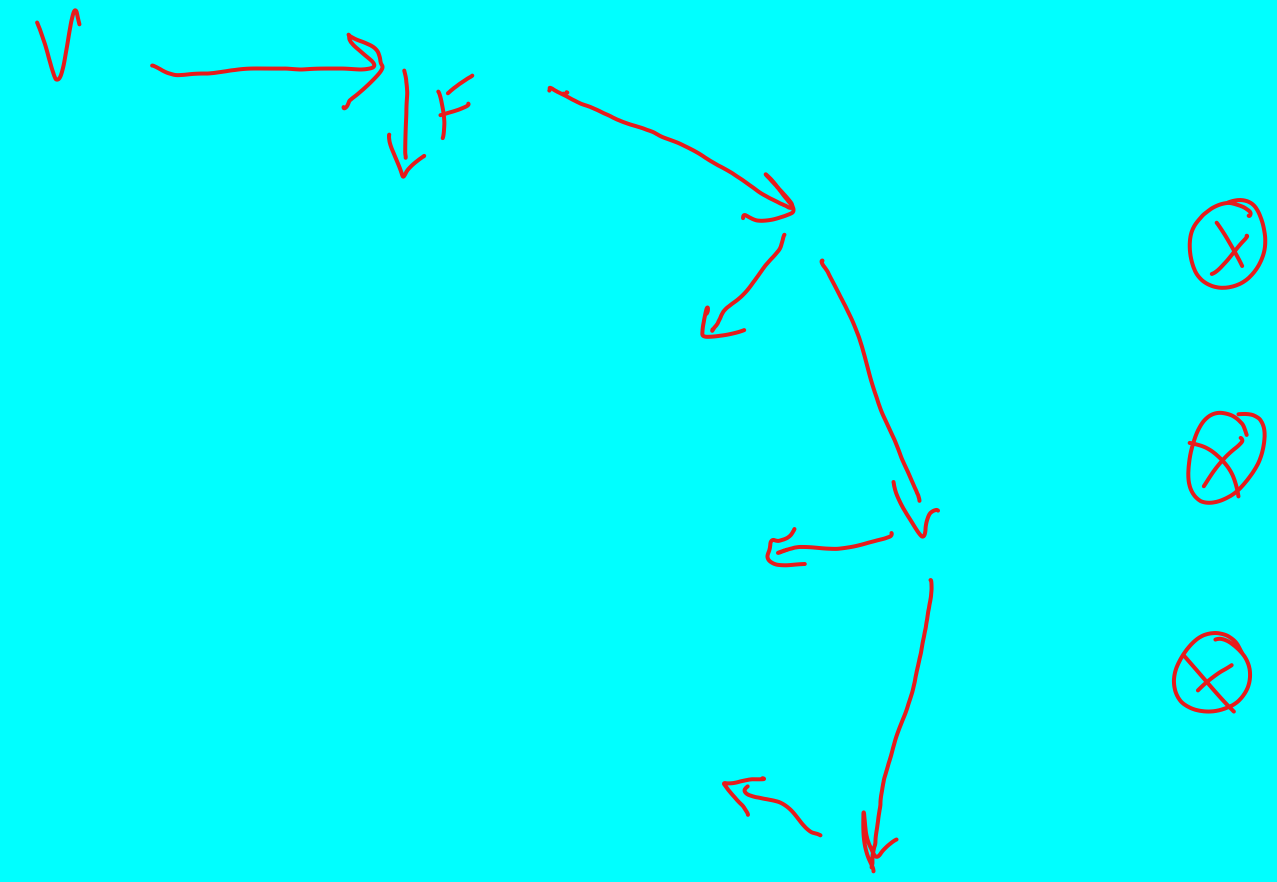


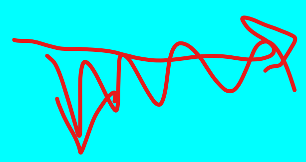
Problem

- A uniform magnetic field of one milliTesla is in the z-direction
- An electron goes through a 1000 V potential drop.
- What path does the electron make in the field?
- What is the radius of the circle that it makes?

$$U_i + K_i = U_f + K_f$$

$$qV + 0 = 0 + \frac{1}{2} m v_f^2$$





$$\vec{F} = q\vec{v} \times \vec{B}$$

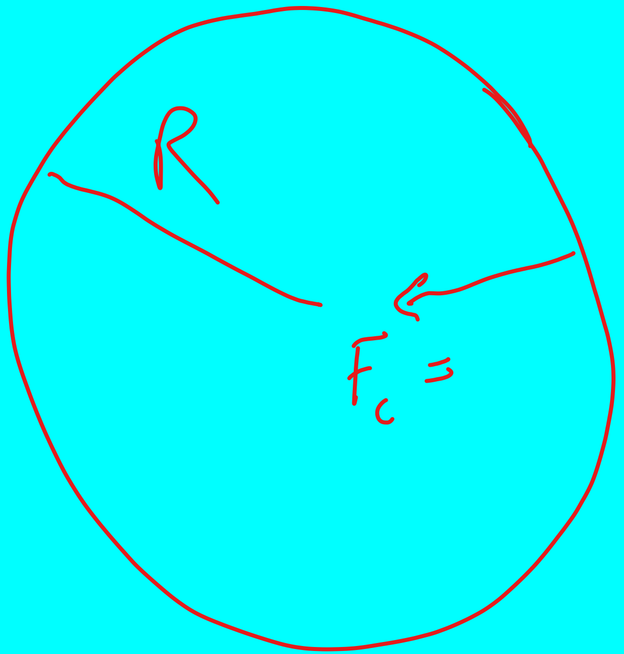
$$B = \mu_0 n I$$

$$F = qvB$$

$$qvB = \frac{mv^2}{R}$$

$$B = \frac{\mu_0 I}{[illegible]}$$

$$\frac{q}{m} = \frac{V}{RB}$$



$$F_c = \frac{mv^2}{R}$$

$$qvB = \frac{mv^2}{R}$$

$$qB = \frac{mv}{R}$$

Torque

- A wrench is 30 cm long and a person exerts 10 N at right angles to it. The torque is?

(A) $30\,\mathrm{N \cdot m}$

(B) $10\,\mathrm{N \cdot m}$

(C) $300\,\mathrm{N \cdot m}$

(D) $3\,\mathrm{N \cdot m}$

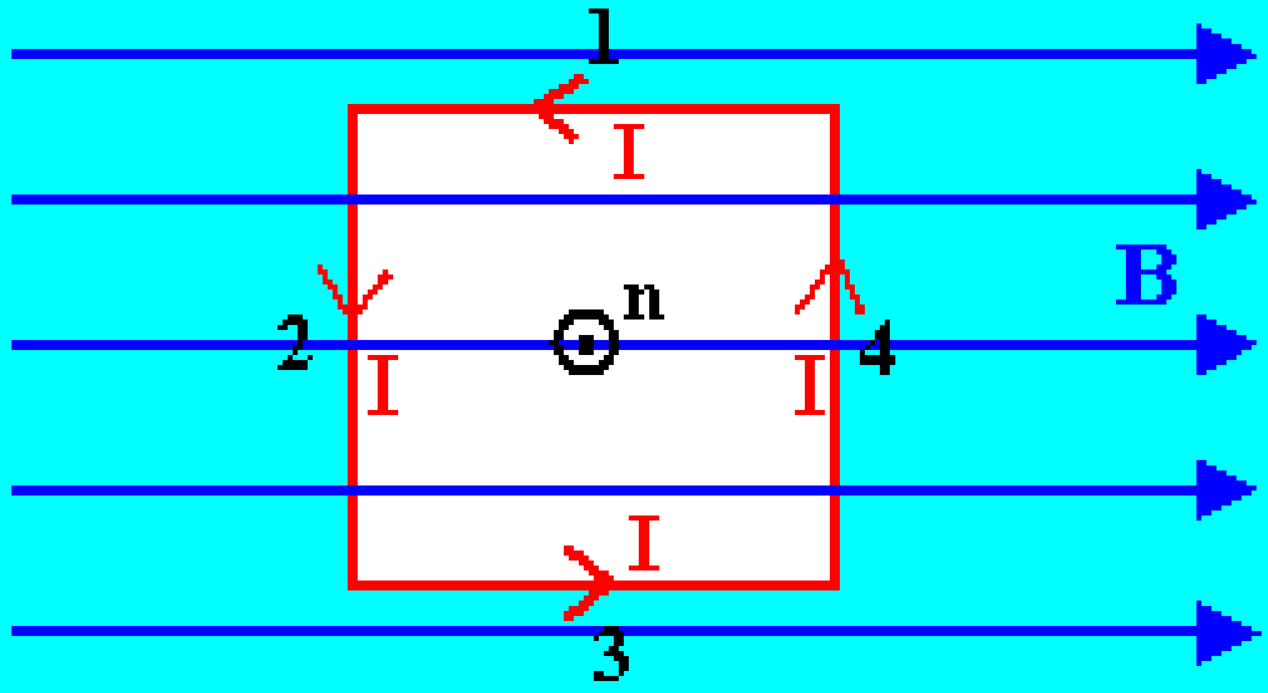
(E) $0\,\mathrm{N \cdot m}$

Magnetic "moment"

$\vec{m} = I\vec{A}$ Def. of Magnetic Moment

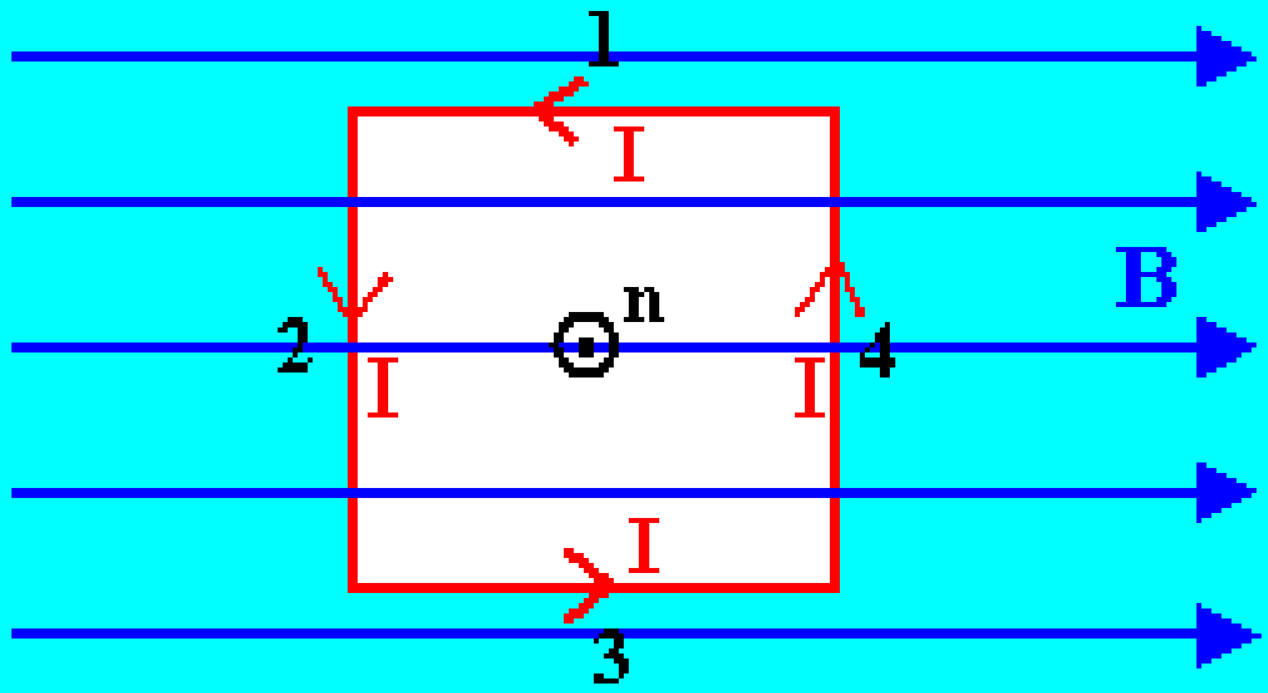
$\vec{\tau} = \vec{r} \times \vec{F}$ Torque definition

$\vec{\tau} = \vec{m} \times \vec{B}$ Torque on a Magnetic Moment



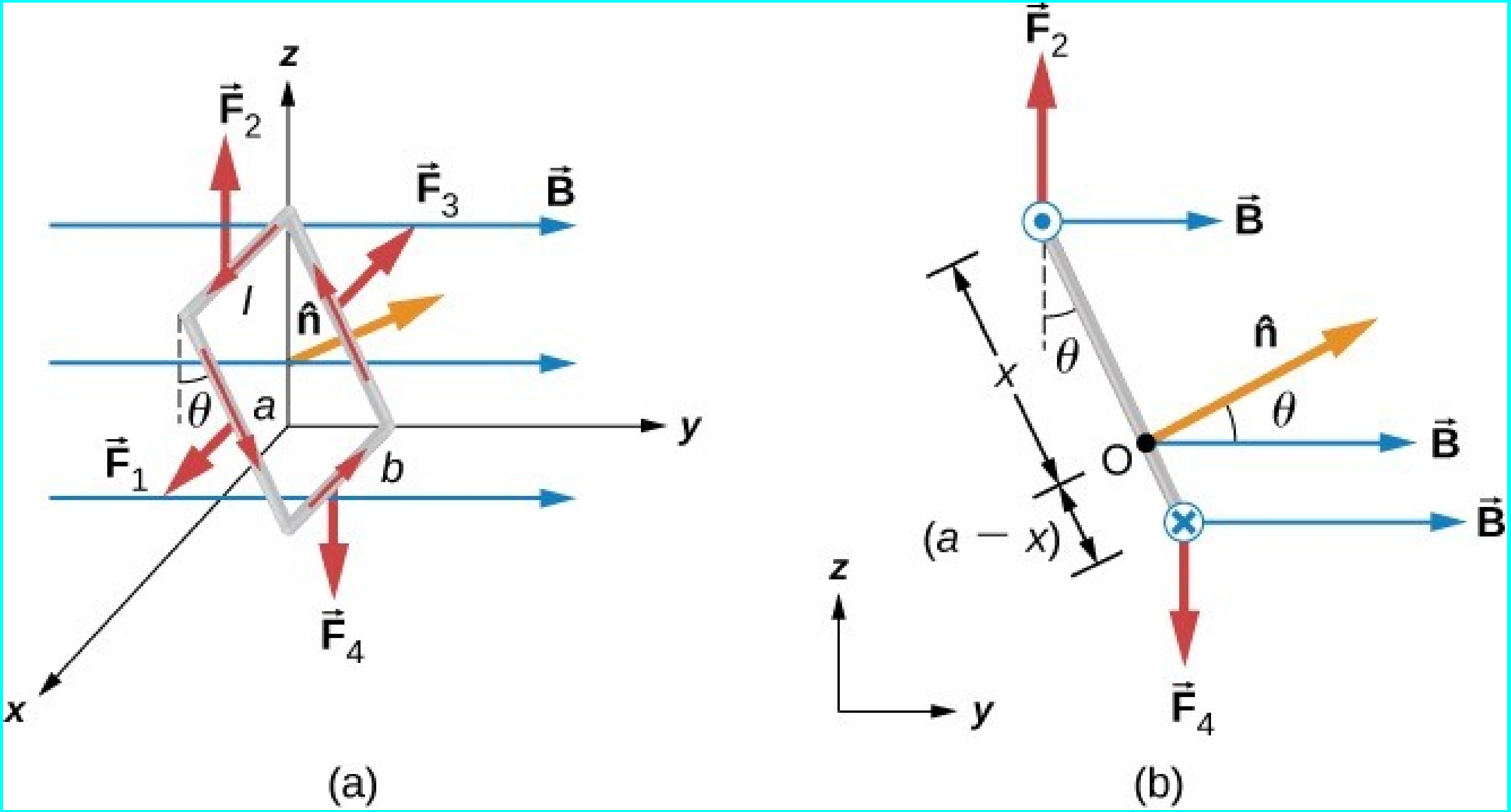
Motors

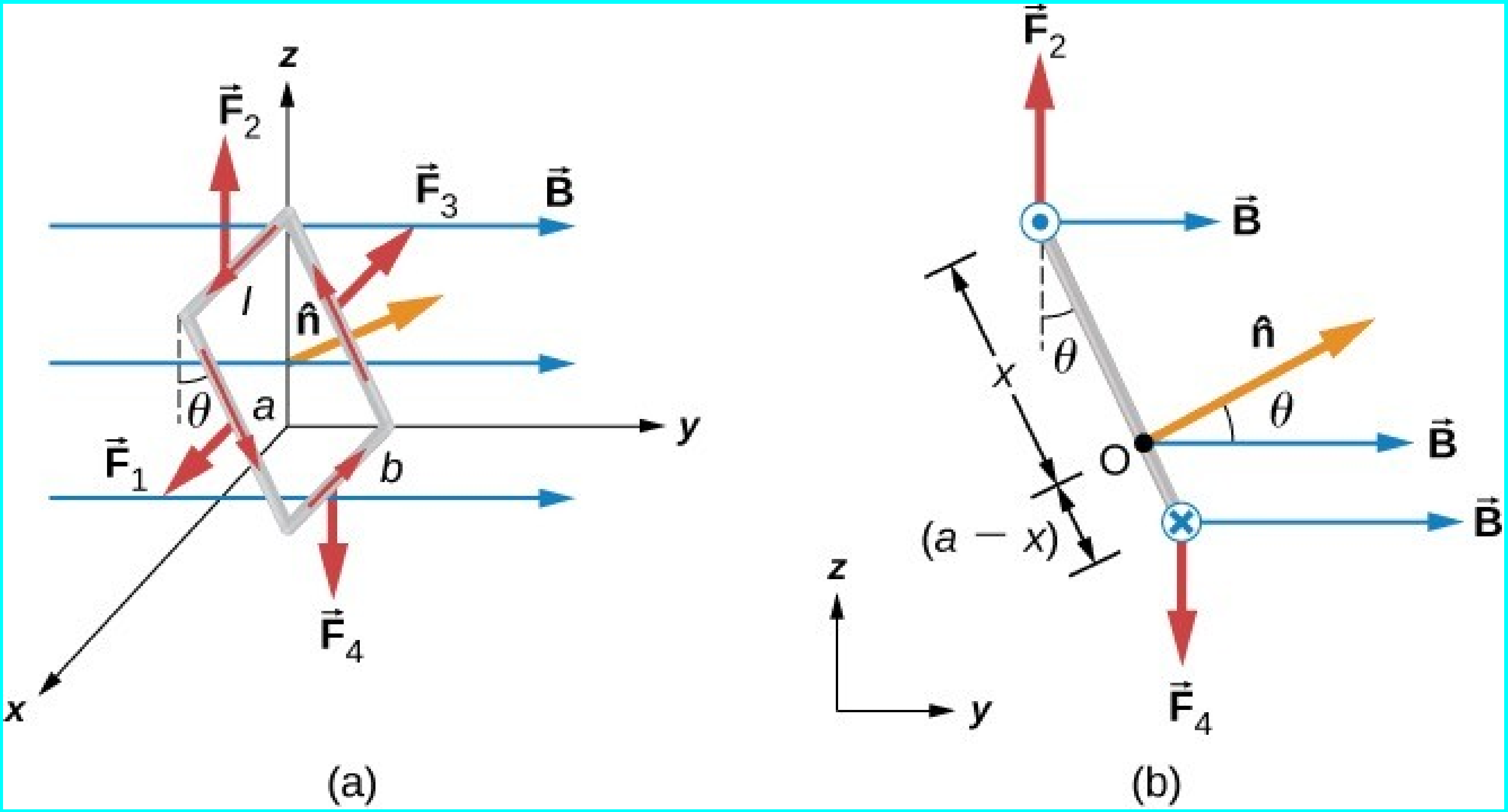
- Are just clever loops of wire in magnetic fields ...



Motors

- Are just clever loops of wire in magnetic fields ...

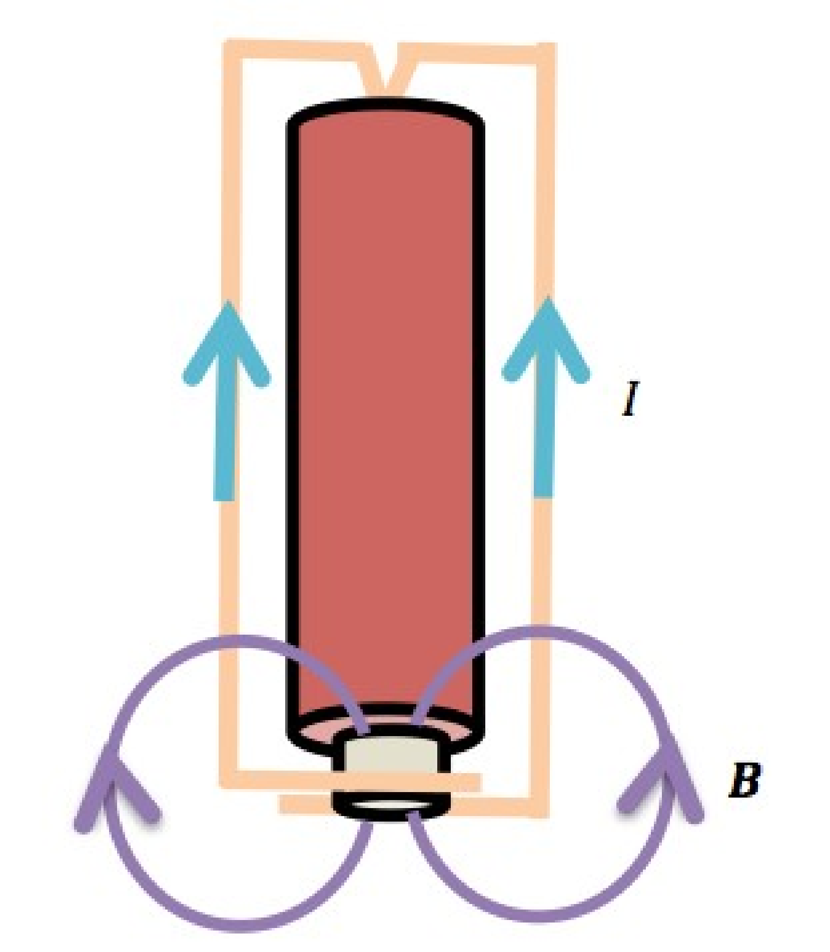


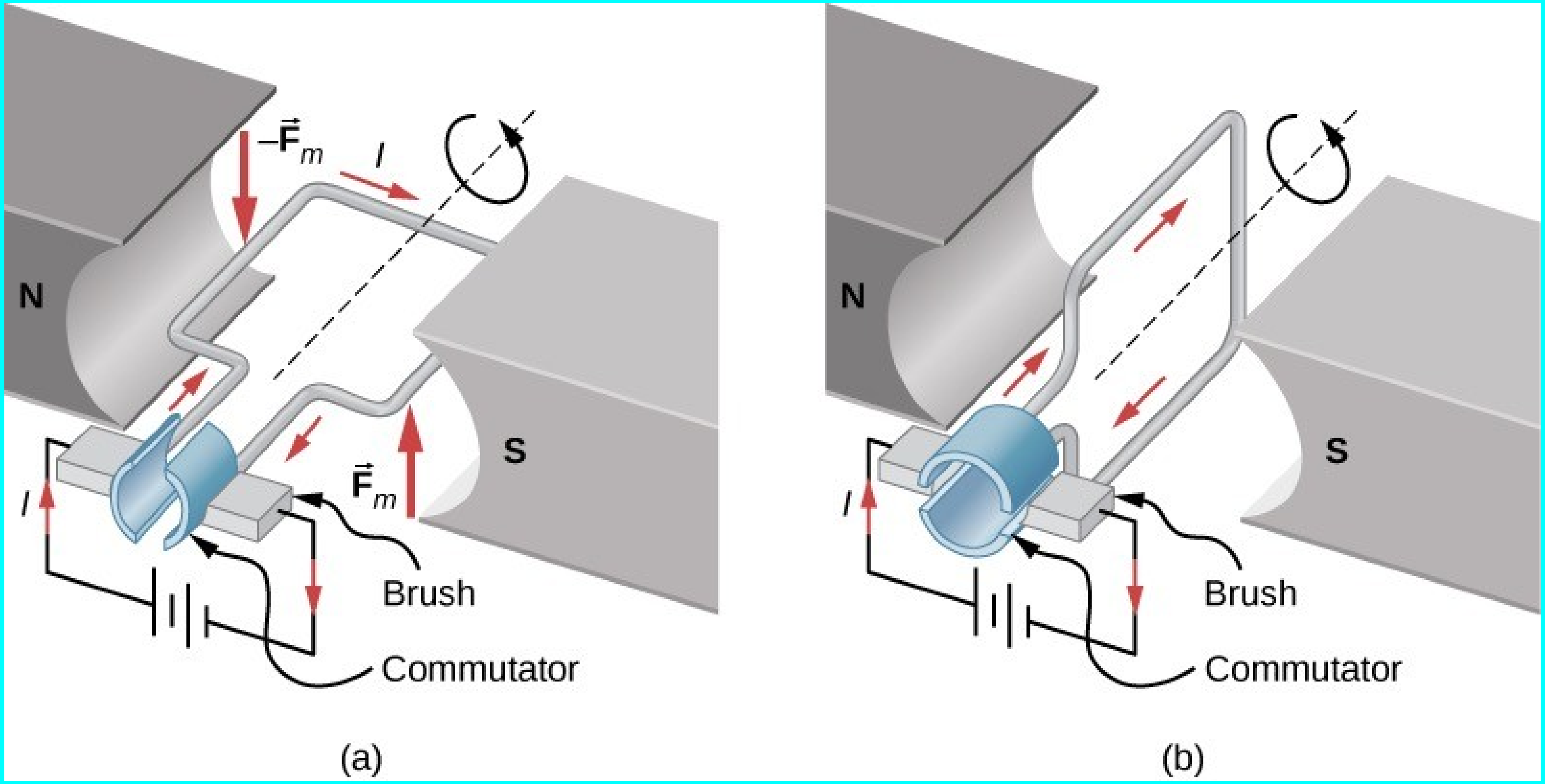

z
$\vec{F}_2$
$\vec{F}_3$
$\vec{B}$
I
n̂
θ
a
y
$\vec{F}_1$
b
x
$\vec{F}_4$
(a)
$\vec{F}_2$
$\vec{B}$
x
θ
n̂
θ
$\vec{B}$
O
(a − x)
$\vec{B}$
z
y
$\vec{F}_4$
(b)

“Homopolar” Motor

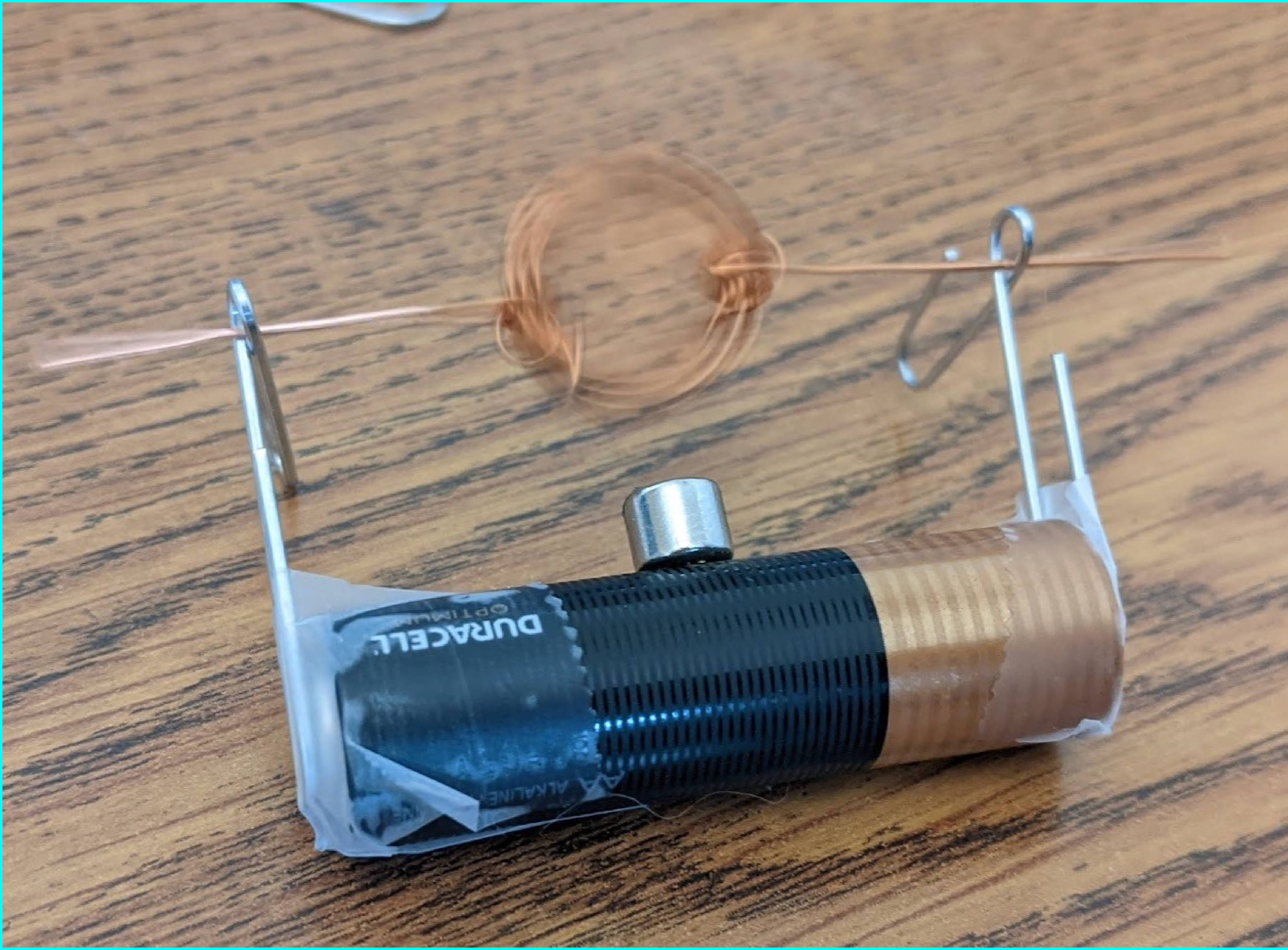
$I \sim vq$

$F = I\vec{L} \times \vec{B}$



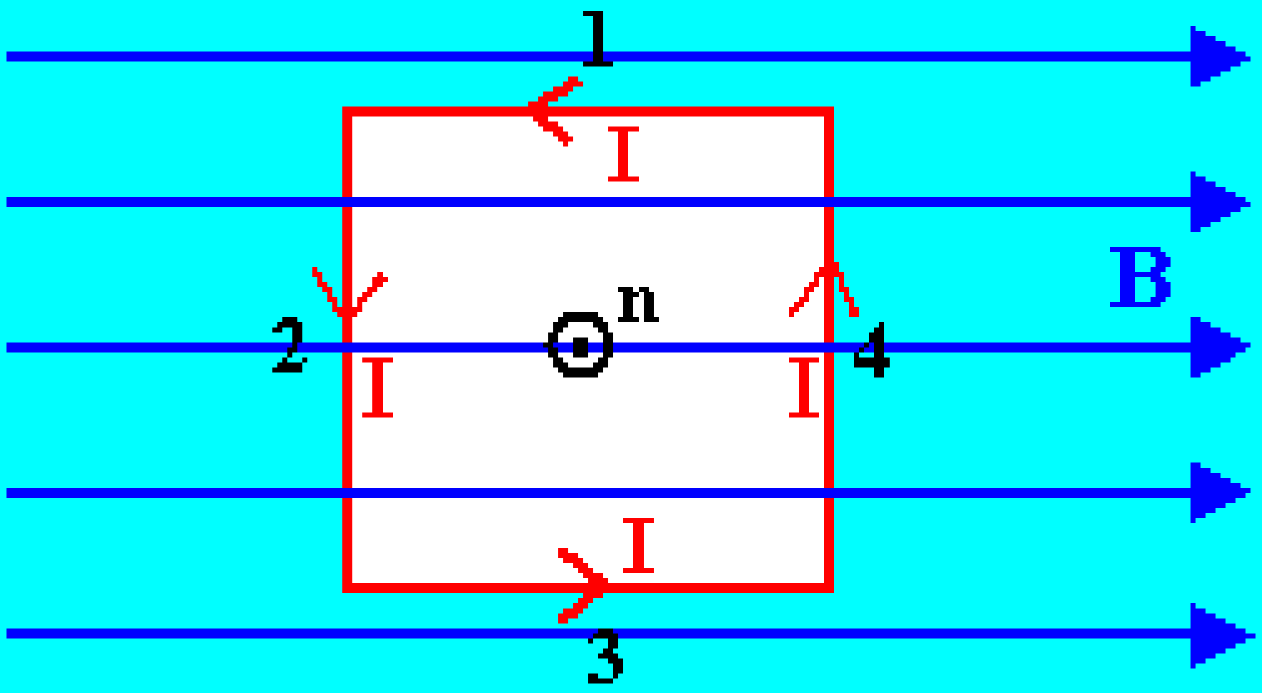


$-\vec{F}_m$
I
N
S
I
$\vec{F}_m$
Brush
Commutator
(a)
N
S
I
Brush
Commutator
(b)


DURACELL

Magnetic “moment”

$$\vec{m} = I\,\vec{A}$$ Def. of Magnetic Moment

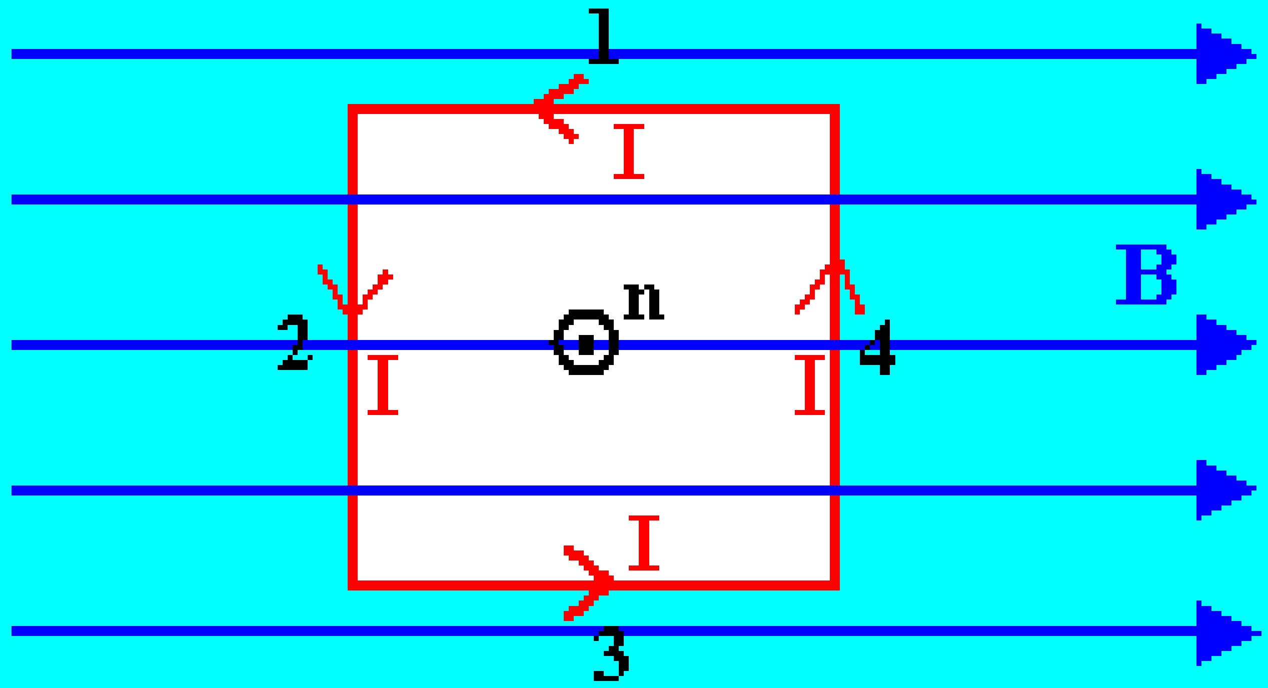


Magnetic “moment”

$$\vec{m} = I\vec{A} \quad \text{Def. of Magnetic Moment}$$

$$\vec{\tau} = \vec{r} \times \vec{F} \quad \text{Torque definition}$$

$$\vec{\tau} = \vec{m} \times \vec{B} \quad \text{Torque on a Magnetic Moment}$$



Electric fields are calculated with Coulomb's law or Gauss's Law

Magnetic Fields are calculated with the Biot-Savart Law or Ampere's Law

$$d\vec{B} = \frac{\mu_0}{4\pi} \frac{I\, d\vec{l} \times \hat{r}}{r^2} \quad \text{Biot Savart}$$

Recap Lecture 21

- Magnetic forces are at right angles to velocity and field
- Superposition works for magnetic fields just like electric fields
- Solenoids are "simple" … they have uniform B-fields inside.
- Motors are clever combos of wire and B
- Charged particles go in circles in magnetic fields
- Torque is cross product of magnetic moment and B
- Ampere's Law and Biot Savart law are used to calculate magnetic fields